Optimized diamond photonic molecule for quantum communications

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In recent years, elementary quantum optical structures, called photonic molecules (PMs), have been carefully studied both experimentally and theoretically [1, 2]. There structures are formed from high quality factor solid-state microresonators (MR). These devices may be integrated with single-photon sources that generate and guide photon flows in a system and high-sensitivity detectors that fix the arrival of a photon and, preferably, its polarization [3]. As for the element base for quantum computation, the main effort of scientists is now focused on the search for the optimal geometry of a solid-state photonic chip [4]. Here, we propose the design of three-unit PM optimized to obtain good transport and dissipation properties.

To design PM supporting optical-band frequencies, one uses photon cells with geometric dimensions on the order of a few microns. MRs supporting whispering gallery modes (e.g. microrings) can form quasi-one-dimensional optical structures. We optimize diamond microring parameters calculating the eigenfrequencies and the electrical field distributions of the single microring in a broad range of inner and outer radii as well as thicknesses.

Analytical consideration of the PM-system composed of three MRs is given within the formalism of tight-binding phenomenological Hamiltonian:

$$H = \sum_{k=1}^{3} (\omega_k - i\kappa_k) a_k^\dagger a_k - \sum_{k=1}^{2} J_{k,k+1} \left( a_k^\dagger a_{k+1} + a_{k+1}^\dagger a_k \right).$$

where $\omega_k$ is the mode frequency of the $k$-th MR ($k = 1 - 3$), $a_k^\dagger$ and $a_k$ are creation and annihilation operators of photons, respectively. $J_{k,k+1}$ is a coefficient of photon hopping between the MRs, $\kappa_k$ is a rate of energy dissipation of the MR mode. Provided that $\omega_k \equiv \omega$ and $J_{k,k+1} = J$ each mode of the single MR splits into three ones of PM with frequencies $\omega_{PM,1,3} = \omega \pm \sqrt{3}J$, $\omega_{PM,2} = \omega$. The electric field profile of PM for the eigenfrequencies $\omega_{PM,1,3}$ has antinodes located along the edge of each ring.

The most common mean for controlling the dynamics of photons in PM is laser. Here we employ the weak laser as a probe for the PM’s spectrum. The probability of one-photon excitation of PM due to laser photon injection is calculated in the steady-state regime. The transmission spectrum was represented by a small number of clearly distinguishable peaks. As the MRs approach each other, the splitting of the peaks increases. It is very desirable to have equal optical field amplitudes in each resonator for some eigenmode of the PM. Our solution consists in following choice of Hamiltonian parameters: $J_{k,k+1} = J$, $\omega_1 = \omega_3 = \omega$, $\omega_2 = \omega + J$. In this case, the mode with the frequency $\omega_{PM,\text{opt}} = \omega - J$ is equally-weighted: $|\psi_{\text{opt}}\rangle = (|1\rangle + |2\rangle + |3\rangle)/\sqrt{3}$.

References


